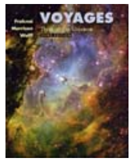
Chapter 17



The Stars: A Celestial Census

17.1 A Stellar Census

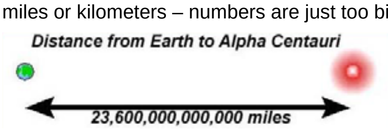
Astronomers want to know:

- *How do stars form?*
- *How long do stars live?*
- *How do stars die?*
- *Do all stars evolve the same way?*

- Stars live for such a long time that there is little to be gained by studying just one for the course of a human life.
- Instead, astronomers need to survey as many stars as possible, to draw conclusions about similarities and differences between the different types that populate the universe.

17.1 A Stellar Census

- Astronomers face many problems studying stars.
- One problem with sampling stars is that they are very far away.
- In fact, they are so far away that astronomers can't use miles or kilometers – numbers are just too big



- Instead, astronomers use a unit of distance called the **light year**.

17.1 A Stellar Census

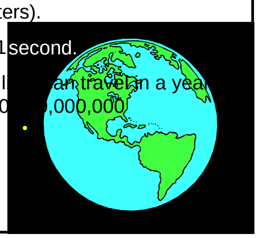
What's a light year?

- What it *isn't*: a light year has nothing to do with time.
- A **light year** is a unit for measuring extreme **distances**.
- You are used to measuring distances in either inches/feet/miles or centimeters/meters/kilometers. These are nice, human increments of distance.
- But try to measure the distance from New York to San Francisco in *inches*.
  - 166,166,668 inches
- Not very practical

17.1 A Stellar Census

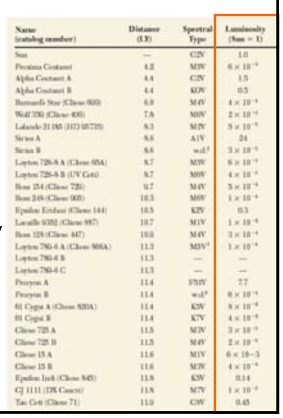
What's a light year?

- Similarly, astronomers can't use miles to measure distances to stars.
- Light travels at 186,000 miles per second (300,000 kilometers per second). Therefore, a **light second** is 186,000 miles (300,000 kilometers).
- That's 8 times around Earth in 1 second.
- A light year is the distance that l… an travel in a year **5,865,696,000,000 miles** (9,460 … ,000,000 kilometers).



17.1 A Stellar Census

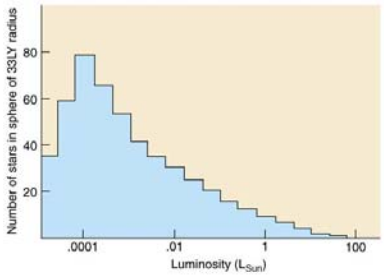
- Appendix 10 (p. 722) lists the stars within 12 light years of the solar system.
- Note luminosity values
  - Are most brighter or fainter than the Sun?
- Stars in our region range from 24x the Sun's luminosity to 1/10,000th.
- The Sun is more luminous than most stars in its immediate vicinity.
- Most common spectral type?



Name (catalog number)	Distance (LY)	Spectral Type	Luminosity (Sun = 1)
Sun	—	G2V	1.0
Proxima Centauri	4.2	M5V	6 × 10[illegible]
Alpha Centauri A	4.4	G2V	1.5
Alpha Centauri B	4.4	K0V	0.5
Barnard's Star (Gliese 699)	6.0	M4V	4 × 10[illegible]
Wolf 359 (Gliese 406)	7.8	M6V	2 × 10[illegible]
Lalande 21185 (HD 95735)	8.3	M2V	5 × 10[illegible]
Sirius A	8.6	A1V	24
Sirius B	8.6	w.d.	3 × 10[illegible]
Luyten 726-8 A (Gliese 65A)	8.7	M5V	6 × 10[illegible]
Luyten 726-8 B (UV Ceti)	8.7	M6V	4 × 10[illegible]
Ross 154 (Gliese 729)	9.7	M4V	5 × 10[illegible]
Ross 248 (Gliese 905)	10.3	M6V	1 × 10[illegible]
Epsilon Eridani (Gliese 144)	10.5	K2V	0.3
Lacaille 9352 (Gliese 887)	10.7	M1V	1 × 10[illegible]
Ross 128 (Gliese 447)	10.9	M4V	3 × 10[illegible]
Luyten 789-6 A (Gliese 866A)	11.3	M5V	1 × 10[illegible]
Luyten 789-6 B	11.3	—	—
Luyten 789-6 C	11.3	—	—
Procyon A	11.4	F5IV	7.7
Procyon B	11.4	w.d.	6 × 10[illegible]
61 Cygni A (Gliese 820A)	11.4	K5V	8 × 10[illegible]
61 Cygni B	11.4	K7V	4 × 10[illegible]
Gliese 725 A	11.5	M3V	3 × 10[illegible]
Gliese 725 B	11.5	M4V	2 × 10[illegible]
Gliese 15 A	11.6	M1V	6 × 10−3
Gliese 15 B	11.6	M3V	4 × 10[illegible]
Epsilon Indi (Gliese 845)	11.8	K5V	0.14
GJ 1111 (DX Cancri)	11.8	M7V	1 × 10[illegible]
Tau Ceti (Gliese 71)	11.9	G8V	0.45

17.1 A Stellar Census

- Appendix 10 in graph form (sample extended to 33 light years)
  - Sun's luminosity = 1
  - Note that most stars have a luminosity less than the Sun



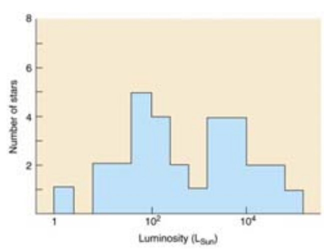
17.1 A Stellar Census

- Appendix 11 (p. 724) shows that most of the brightest stars in the sky are not among the closest.
- Most are hundreds of light years away.
  - The farthest star listed is 3,000 light years away.
- Most common spectral type?

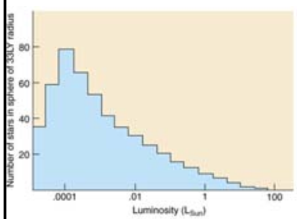
Name[1]	Luminosity (Sun = 1)	Distance[2] (LY)	Spectral Type
Sirius (α CMa)	24	8.6	A1V
Canopus (α Car)	7.3×10^3	228	F0II
Alpha Centauri	2	4	G2V
Arcturus (α Boo)	187	37	K1.5II
Vega (α Lyr)	50	25	A0V
Capella (α Aur)	145	42	G8III
Rigel (β Ori)	6×10^4	772	B8Ia
Procyon (α Cmi)	7	11	F5IV-V
Betelgeuse (α Ori)	7×10^5	427	M1Iab
Achernar (α Eri)	2800	144	B3V
Beta Centauri	6.5×10^4	525	B1III
Altair (α Aql)	10	17	A7V
Aldebaran (α Tau)	450	65	K5III
Spica (α Vir)	1.2×10^4	262	B1III
Antares (α Sco)	8.5×10^3	604	M1.5Ib
Pollux (β Gem)	40	34	K0III
Fomalhaut (α PsA)	16	25	A3V
Deneb (α Cyg)	2.4×10^5	3228	A2Ia
Beta Crucis	1.6×10^4	352	B0.5IV
Regulus (α Leo)	230	77	B7V

17.1 A Stellar Census

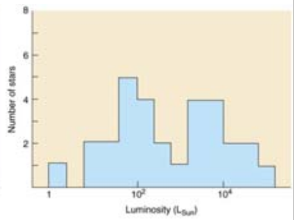
- Graph plotting the luminosity of the 30 brightest stars in our sky.
- Note the difference in the range of luminosity.
- Are most more or less luminous than our Sun?



17.1 A Stellar Census



Luminosities of Nearby Stars



Luminosities of the Brightest Stars

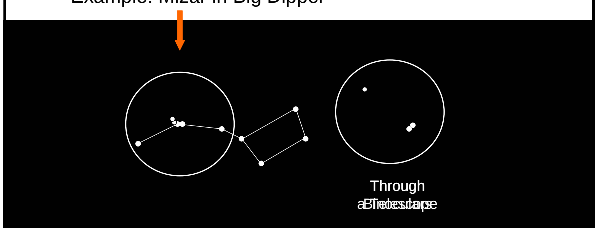
- Where does the Sun fall in each of the two plots?

17.1 A Stellar Census

- Conclusion: most of the brightest stars in the sky are NOT the closest ones
  - The most luminous stars = 100,000x the Sun's luminosity
    - Very rare
    - These are also among the most massive stars
    - How do we know?

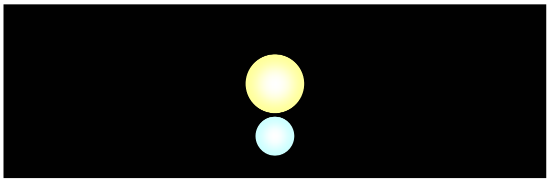
17.2 Measuring Stellar Masses

- How does the Sun's mass compare to other stars?
- The best information about the masses of other stars comes from studying binary stars
- Some stars form in pairs or groups all orbiting a common center of gravity
- Example: Mizar in Big Dipper



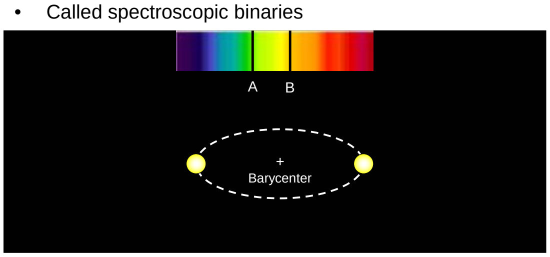
17.2 Measuring Stellar Masses

- Of the 59 stars within 16 LY of the Sun, 27 are binary stars.
- Astronomers can calculate the masses of the stars based on measurements of their orbits.



17.2 Measuring Stellar Masses

- Some binary stars are so close that we can't resolve them through telescopes.
- Astronomers can detect two different stars by examining the combined spectra.
- Called spectroscopic binaries



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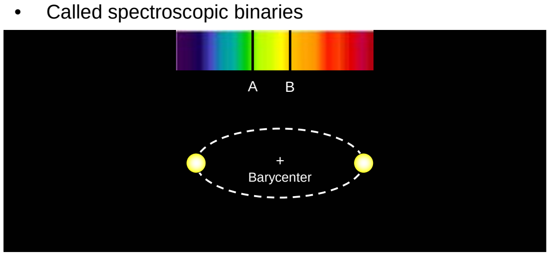


17.2 Measuring Stellar Masses

Determining Masses from the Orbits of Binary Stars

- Johannes Kepler (1571-1630) found that orbital period, distance, and mass are all interrelated:

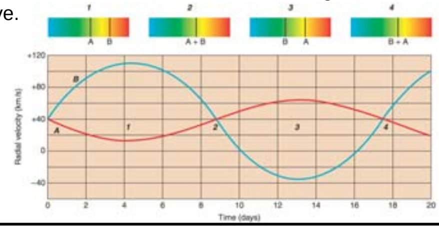
$$D^3 = (M_1 + M_2)P^2$$

  - D = orbital distance in Astronomical Units
    - Can find this out from the Doppler effect
  - P = period in years
    - Can be measured directly
  - $M_1 + M_2$ = sum of masses in units of the Sun's mass
- So, once astronomers know two of the variables, they can calculate the third (sum of the masses)

17.2 Measuring Stellar Masses

Determining Masses from the Orbits of Binary Stars

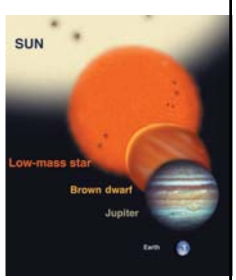
- By plotting radial velocities (in/out) of a star and comparing it to a binary's spectrum, astronomers can calculate each star's individual mass as a proportion of the sum of the masses.
- This method is critical to our understanding of how stars evolve.



17.2 Measuring Stellar Masses

The Range of Stellar Masses

- The Sun is often referred to as a "typical" star in terms of size.
- Range in mass:
  - Smallest stars = 1/12th mass of Sun
  - Objects to 1/100th mass of Sun = brown dwarfs
    - May produce deuterium via nuclear reaction, but are not hot enough to force protons to form helium
  - <1/100th mass of Sun = planets
    - Jupiter = 1/1000th mass of Sun

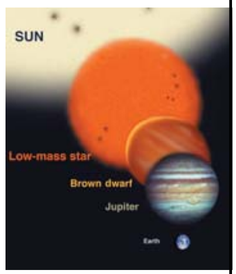


17.2 Measuring Stellar Masses

The Range of Stellar Masses

- Largest stars = 200x mass of Sun
  - Extremely rare
- Most stars are less massive than our Sun

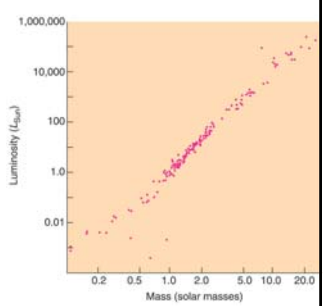
- In our neighborhood:
  - Within 30 LY, no star is greater than 4x mass of Sun



17.2 Measuring Stellar Masses

Mass-Luminosity Relation

- There is a definite relationship between a star's mass and its luminosity.
  - The more massive the star, the higher its luminosity.
- ~90% of all stars fall along a line from lower left to upper right on mass-luminosity chart.



17.3 Diameters of Stars

- How big is the Sun?
  - 864,000 miles in diameter
- How do we know?
  - The Sun covers about ½ degree of sky.
  - By knowing this and its distance away, we can calculate its diameter using basic trigonometry.
- But since the stars are so far away, they only appear as points – diameters can't be calculated directly
  - Two methods used to determine diameters

17.3 Diameters of Stars

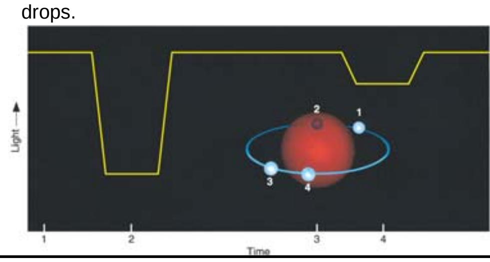
Method #1: Stars Blocked by the Moon

- Timing precisely how long it takes for a star to disappear behind the Moon's or a planet's disk to determine angular diameter.
- This method is limited to bright stars that lie along the Moon's path in the sky (called the ecliptic).

17.3 Diameters of Stars

Method #2: Eclipsing Binary Stars

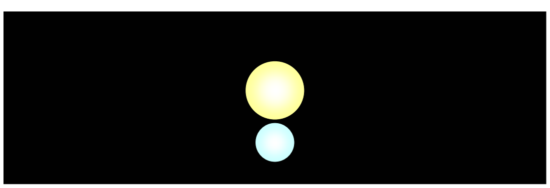
- Some binary stars are lined up in such a way that one passes in front of the other as they orbit.
- When one star is hidden, total luminosity of system drops.



17.3 Diameters of Stars

Method #2: Eclipsing Binary Stars

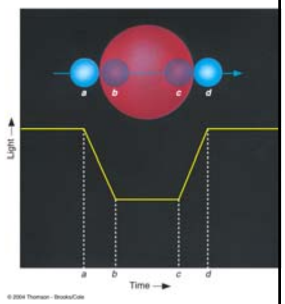
- Famous example: Algol in Perseus
  - Eclipse occurs every 2 days 20 hours 49 minutes
  - Spectroscopic binary: stars are too close to be resolved through a telescope



17.3 Diameters of Stars

Method #2: Eclipsing Binary Stars

- By timing when one star is completed blocked by the other (using their spectra), astronomers can determine the diameter of the blocking star (b-c).
- Knowing that, they can determine the speed of the smaller star.
- Knowing that, they can determine its diameter by how quickly it disappears behind the larger star (a-b).



17.4 The H-R Diagram

- Table 17.1 summarizes how astronomers determine characteristics of stars
- When many of these became known, astronomers began to look for patterns in the data.

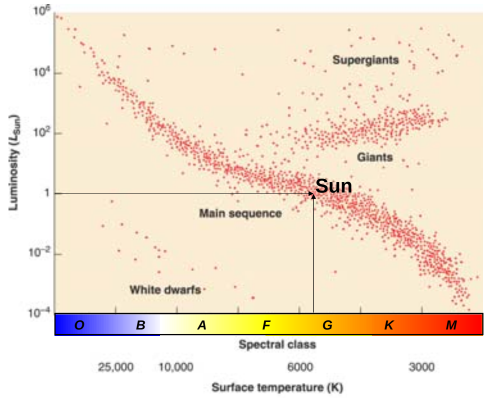
TABLE 17.1 *Measuring the Characteristics of Stars*

Characteristic	Technique
Surface temperature	1. Determine the color (very rough). 2. Measure the spectrum and get the spectral type.
Chemical composition	Determine which lines are present in the spectrum.
Luminosity	Measure the apparent brightness and compensate for distance.
Radial velocity	Measure the Doppler shift in the spectrum.
Rotation	Measure the width of spectral lines.
Mass	Measure the period and radial-velocity curves of spectroscopic binary stars.
Diameter	1. Measure the way a star's light is blocked by the Moon. 2. Measure the light curves and Doppler shifts for eclipsing binary stars.

17.4 The H-R Diagram

- In 1911, Danish astronomer Ejnar Hertzsprung found that stars' temperatures were related to their luminosity.
- In 1913, American astronomer Henry Russell independently plotted the luminosities of stars against their spectral types (which denote surface temps).
- This important co-discovery led to the creation of a very important diagram: the H-R Diagram.

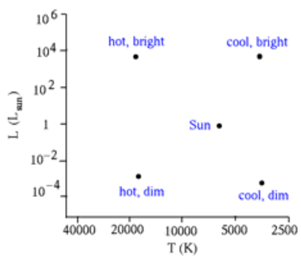
17.4 The H-R Diagram



17.4 The H-R Diagram

Main Sequence

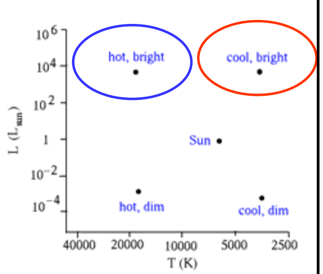
- 90% of all stars lie on the Main Sequence
- Where they lie along the Main Sequence depends on their ***temperature*** and ***luminosity***
- These depend on each star's mass
- Upper left: hottest, most massive stars
- Lower right: coolest, least massive stars



17.4 The H-R Diagram

Giant stars

- Upper left: **Blue giants**
  - Extremely hot
  - Most luminous
- Upper right: **Red giants and supergiants**
  - Cool
  - Super-massive



17.4 The H-R Diagram

Dwarf stars

- Lower right: **Red dwarfs**
  - Dimmest, coolest stars
  - Most common stars in universe
- Lower left: **White dwarfs**
  - Very dim
  - Very hot!!
  - Why? Extremely dense
  - Teaspoon of material would weigh 50 tons here on Earth